Deciphering the oscillation spectrum of γ Dor and SPB stars

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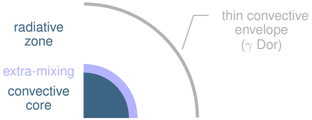
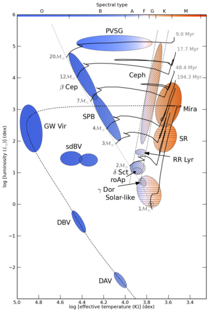
PNPS: SISROT (D. Reese)

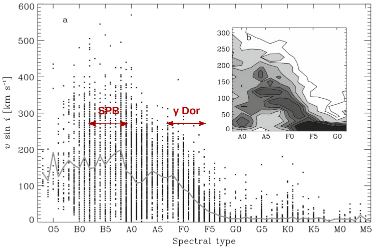
- **γ Dor: 1.3 - 2.0 $M_\odot$ / SPB: 3 - 8 $M_\odot$** (high-order g modes)





(from P.I. Pápics' PhD thesis)

- **Hundreds** of them in the *Kepler* field of view



- **Moderate to fast rotators**

(adapted from Royer 2009)

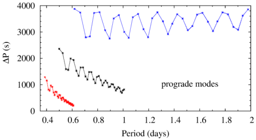
Gravity modes

- **No rotation:** high-order g modes ($n \gg \ell$) regularly spaced in period (Tassoul 1980)

$$P_{n,\ell,m} \approx \frac{P_0(n+\epsilon)}{\sqrt{\ell(\ell+1)}} \qquad \Delta P_\ell = P_{n+1,\ell,m} - P_{n,\ell,m} \approx \frac{P_0}{\sqrt{\ell(\ell+1)}}$$

Buoyancy travel time $$P_0 = 2\pi^2 \left(\int_{\mathcal{C}} \frac{N_{\rm BV}}{r} \mathrm{d}r \right)^{-1}$$

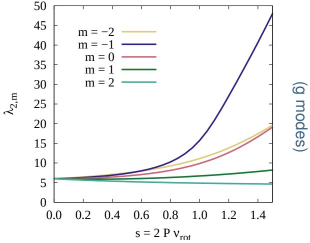
- **Rotation**:
  Coriolis force / centrifugal distortion



(from Ouazzani+ 2017)

Our approach

- **The hypotheses of the TAR** (Eckart 1960):
  - uniform rotation
  - no centrifugal distortion
  - $\boldsymbol{\Omega_h = 0}$



- **Asymptotic formulation** $(n \gg \ell)$ **in the co-rotating frame**,

$$P^{\rm co}_{n,\ell,m} \approx \frac{P_0(n+\epsilon)}{\sqrt{\lambda_{\ell,m}(s)}},$$

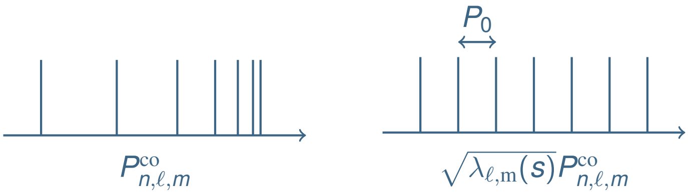
$\lambda_{\ell,m}$ eigenvalues of Laplace's tidal equation

$s = \frac{2P^{\rm co}_{n,\ell,m}}{P_{\rm rot}}$ spin parameter

The stretching method

- Stretching the pulsation periods ⇒ **regular spacing pattern**

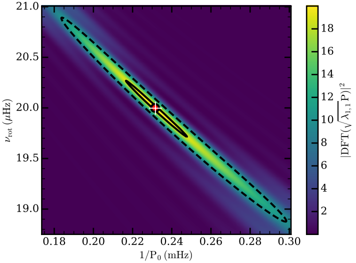
$$P^{\rm co}_{n,\ell,m} \rightarrow \sqrt{\lambda_{\ell,m}(s)}\,P^{\rm co}_{n,\ell,m} \approx n(P_0 + \epsilon)$$



- The stretching function depends on ℓ, m and $\nu_{\rm rot}$.

Searching for regularities

1. List of peak frequencies (e.g. pre-whitening)
2. Pick a guess for (ℓ, m), choose a range of $\nu_{\rm rot}$
3. For each value of $\nu_{\rm rot}$,
   - Change to the co-rotating frame
   - Stretch the pulsation periods
   - Compute the DFT
4. Stack the DFT spectra by increasing $\nu_{\rm rot}$
5. Maximum of PSD is significant ?



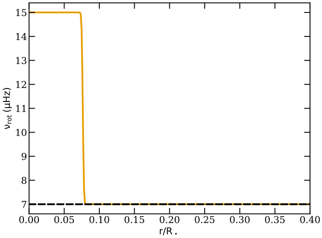
Tests on synthetic spectra

γ Dor, 1.86 $M_\odot$, mid-MS, ℓ = 1, m = -1, 0, 1

- Stellar structure: 1D CLES models (Scuflaire+ 2008) + *ad hoc* rotation profile
- Oscillation modes: 2D complete calculations with ACOR (Ouazzani+ 2012,2015)

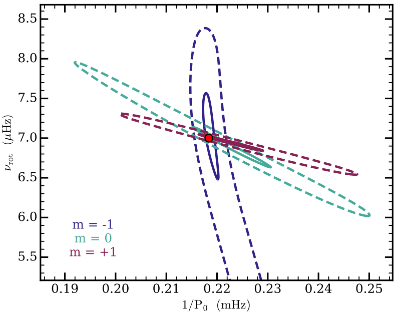
2 test cases:

- uniform rotation
- differential rotation



Uniform rotation

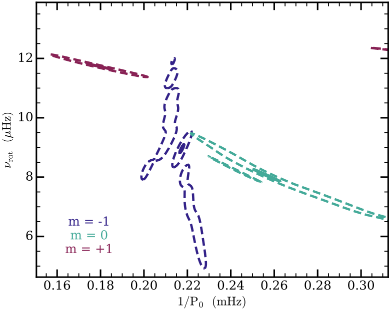
- Inputs: $\nu_{\rm rot}$ = 7 μHz, P_0 = 4579 s



- Only a few % of difference with the input values.
- Both the asymptotic and TAR approximations contribute to it.

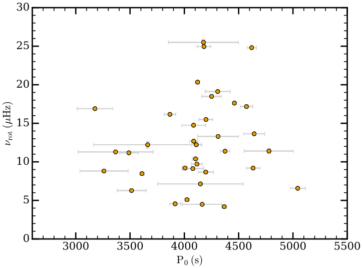
Differential rotation

- Inputs: 15 μHz (core) / 7 μHz (envelope), P_0 = 4579 s



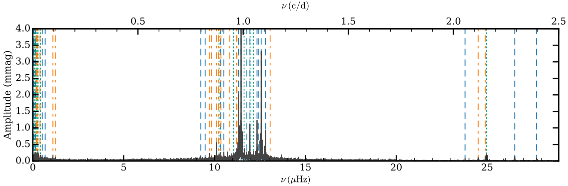
- Signature of differential rotation
- Consistent with the mode cavities (prograde modes go deeper)

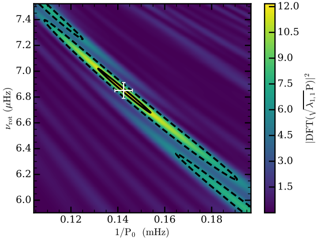
Application on *Kepler* γ Dor stars



- 36 γ Dor stars:
  4 stars of Ouazzani+ 2017
  32 from Van Reeth+ 2016
- $\nu_{\rm rot}$ and P_0 estimated from prograde dipole modes.
- Constraints on angular momentum transport
  (R.M. Ouazzani's talk)

- $\nu_{\rm rot} = 6.85 \pm 0.07\ \mu$Hz, $P_0 = 7018 \pm 190$ s





- compatible with Pápics+ 2017

$$\nu_{\rm rot} = 7.3 \pm 0.5\ \mu\text{Hz}$$
$$P_0 = 8260^{+1400}_{-1300}\ \text{s}$$

Summary and prospects

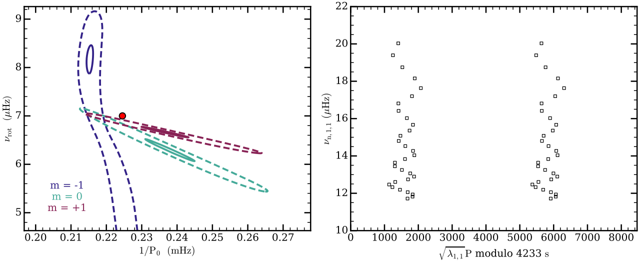
A stellar-model-independent method to get the mode IDs, near-core ν_{rot} and P_0 of γ Dor and SPB stars.

Prospects

- Extend our sample of γ Dor and SPB stars with measured ν_{rot} and P_0 (automation ?) to constrain **angular momentum transport**
- **Differential rotation**: what do we measure exactly? Is the TAR sufficient?
- **Rossby modes** are predicted by the TAR and observed in some γ Dor stars. (VanReeth+ 2016, Saio+ 2017)

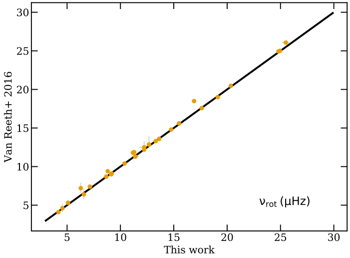
Buoyancy glitch

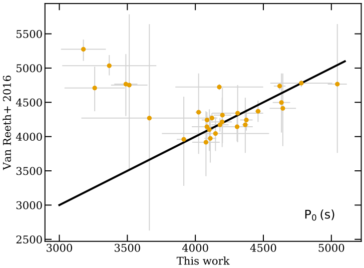
- Inputs: ν_{rot} = 7 μHz, P_0 = 4453 s



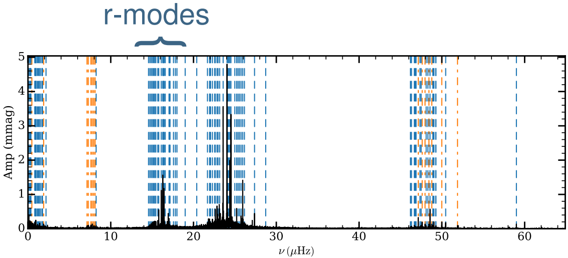
- Max error: 17% on ν_{rot} (retrograde)
  9% on P_0 (zonal)

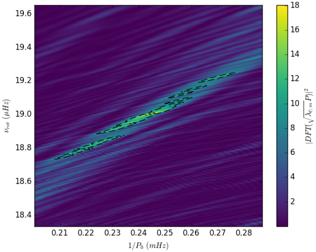
Comparison with Van Reeth+ 2016

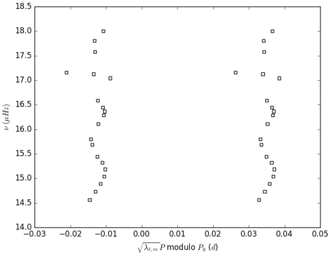




- VR16 modelled period spacing patterns using a direct approach
  (model-dependent, asymptotic TAR)
- Both methods agree on ν_{rot}
- P_0 not always compatible


r-modes
Amp (mmag)
ν (μHz)


ν_{rot} (μHz)
$1/P_0$ (mHz)
$|DFT(\sqrt{\lambda_{\ell,m}}P)|^2$


ν (μHz)
$\sqrt{\lambda_{\ell,m}}P$ modulo P_0 (d)

Rossby modes: an example (γ Dor)